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LAYOUT DESIGN FOR MASS CUSTOMISATION PRODUCTION: AN ACTION BASED CASE STUDY IN A SMALL ENTERPRISE

ABSTRACT

Due to intense competition between mass production manufacturers, they offer much more personalized product to the consumers. It used to be tremendously expensive, but the chance opened up by the technology advancement causing the idea of mass customization to be much more feasible. The concept of Made to Stock (MTS) is now slowly shifting to Made to Order (MTO) type as it has better demand nowadays.

This study was carried out to design a production layout for an MTO furniture enterprise taking onto consideration the ergonomic risk factors in order to ensure a better efficiency and safer production place. The previous place of the enterprise had so many issues hence an action research from the previous production place to a much proper one was carried out which includes studies of the layout and the dust control system. It was found that functional layout would suit the best for the small enterprise.

The importance of having an efficient production place is to shorten and stabilize the timeline of the orders. Hence the production timeline was also observed and some feedback from the customers became a quantitative responding variable to the action research. However it was found that, these two may not be a strong indicator to measure the efficiency of the production place due to many other changing factors during the period.

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ABSTRAK

Disebabkan oleh persaingan sengit antara pengilang pengeluaran besar-besaran, mereka menawarkan lebih banyak produk yang diperibadikan kepada pengguna. Dahulu ianya sangat mahal, tetapi peluang yang dibuka oleh kemajuan teknologi menyebabkan idea *'mass customization'* menjadi lebih cerah. Konsep '*Made to Stock'* (MTS) kini perlahan-lahan beralih ke jenis '*Made to Order'* (MTO) kerana ia mempunyai permintaan yang lebih baik pada masa kini. Kajian ini dijalankan untuk merekabentuk susun atur pengeluaran untuk sebuah syarikat perabot MTO dengan mengambil kira faktor risiko ergonomik untuk memastikan kecekapan yang lebih baik dan tempat pengeluaran yang lebih selamat. Tempat usaha terdahulu mempunyai begitu banyak isu, jadi penyelidikan tindakan dari tempat pengeluaran terdahulu kepada yang lebih baik telah dijalankan yang merangkumi kajian tata letak dan sistem kawalan debu. Adalah didapati susun atur fungsian adalah sesuai dengan perusahaan kecil. Kepentingan untuk mempunyai tempat pengeluaran yang cekap adalah untuk memendekkan dan menstabilkan garis masa pesanan. Oleh itu, garis masa pengeluaran juga diperhatikan dan beberapa maklum balas daripada pelanggan menjadi pemboleh ubah tindak balas kuantitatif kepada penyelidikan tindakan. Walau bagaimanapun, didapati bahawa kedua-dua ini tidak boleh menjadi penunjuk yang kuat untuk mengukur kecekapan tempat pengeluaran disebabkan oleh banyak faktor perubahan yang lain dalam tempoh tersebut.

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CHAPTER 1: INTRODUCTION

1.1 Background

Furniture industry nowadays is slowly shifting from the days of mass production and trend-dictated design to custom made pieces. In order to sustain, manufacturing industries have to understand due to the intense competition in the industry, market is now entering to highly empowered consumers in which they have stronger says even with a similar price. Products or services that able to cater the demand and requirement for consumer will have bigger possibility to win the market.

Custom made furniture making in particular used to be very rare and each piece can be tremendously expensive. With the growing demand of customize furniture especially among the younger generation, small entrepreneur started to set up their own furniture workshop. Due to lacking of interest in made to stock (MTS) furniture among consumers, they are willing to wait for made to order (MTO) type as long as it fully meets their requirements. However, they are not necessarily willing to pay the extra cost as much as the cost needed to be bare by the enterprise for the delay. Hence, it is very important to find a way to shorten the lead time in order to sustain the business.

Carpent Studio is a small enterprise that provide carpentry and steel works for home improvement comprises of engineering and industrial design graduates. It is a bespoke furniture studio in which now (at the time of the study) still using the conventional type of machining. They customized each of the order to the extent of the machines and labor's capabilities. They have to treat each of the order individually and most of the fabrication

process of the furniture require high skilled craftsmanship and manual operations. Hence, causing the lead time to be very long which can be about 3 to 5 weeks for each. Although the idea of offering customers fully customization for their furniture might sound uneconomical, but it is the selling point for the small enterprises.

In order to sustain, there are two possibilities, either they move towards mass production in which shifting towards MTS type of furniture business or maintaining the customization value and stay as MTO type of business but doing it in a mass scale. If they go toward the first possibility in which they expand and become mass production manufacturer, surely they have to face the same current issue, fading in market demand. While, going for the latter is possible although it is not fully proven feasible just yet. Hence, directionally, the expansion of small customize furniture enterprises has to be moving towards mass customization furniture manufacturer if they want to be able to compete in the industry. In the yesteryears, the idea of mass customization might not be feasible, but now with the saturation of the industry and the opportunity or potential opened up by technology advancement, the concept is now very much more achievable. It is only the matter of right strategy to deliver the product just in time.

Shifting a furniture company towards mass customization can be look from two outsets either from a mass production manufacturer or from a handcrafted industry. In this particular study, we are looking at the latter case. The main objective of the study is to design an ergonomic woodworking workshop. It is believed that, a well-designed workshop will give significant difference in terms of the safety and efficiency of the workplace hence become the first important step in moving towards mass customization manufacturer.

1.2 Problem Statement

The feasibility of Made to order (MTO) furniture industry mainly depends on three main key point which are the level of customization, the fabrication timeline, and the costing. These three key points are interconnected to each other. Increment in the level of customization will basically increase the fabrication timeline and costing. Hence a flexible and efficient production place would be promising. One of the way to achieve it is by implementing ergonomics in the MTO production place. The question is how to implement ergonomics in MTO particularly in small Enterprise in order to improve the three main key points mentioned earlier.

1.3 Objectives

This study was carried out to ergonomically design a customize furniture woodworking workshop in order to maximize the efficiency and safety level of the workplace by:

1. Identifying key ergo issues that affects MTO SMI of current production line
2. Design and implement new MTO SMI Production line to improve ergo issue
3. Verify the effectiveness of the new production line

1.4 Scope of the project

The project will only consider the former and newly moved production place of Carpent Studio which both located at Shah Alam, Selangor. The size of the workplace was based on the actual measurement but certain of the workstation at the new place was made up but

thought necessary for future expansion due to the lacking of machinery capacity for now of the startup woodworking workshop.

1.5 Organizational of the Report

The first chapter gives some background of the study which briefly explains the nature of business for Carpent Studio and the issues it currently facing. The main objectives that wanted to achieve by the end of the study were listed out.

The second chapter on the other hand, is the literature review that explains in much more details on the concept of mass customization as it needed to be understood so that the whole study will be based on moving towards that. It also explain the importance of ergonomic study of a production place and the ergonomic risk factors that need to be taken into account. Thorough research on proper layout and method in designing an efficient workplace and dust management system were explained before the design process that documented in the later chapter.

The third part of the study is the research methodology to explain the action research that being carried out. Data were collected from both of the workplace as well as questionnaires to the previous customers.

The fourth part of the study is a discussion on the former workplace emphasizing on the layout, production flow and the issues aroused during the time. Subsequently, a better workplace for the newly moved production floor was designed.

As a continuation from the chapter 4, the data collected during both of the workplaces were being compared and discuss. Comparisons for both of the workplaces are also being made in terms of the production timeline and customer's satisfaction.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter explains the concept of mass customization and how it differ from the mass production. This MTO type of business require different needs than the latter hence the ergonomic need from the outsets of small enterprise are being identified which includes the Work-related musculoskeletal disorder (WMSD), design of workbenches, hand tools design and the dust control system.

2.2 Mass Customization and mass production in Furniture Industry

The concept of mass customization (MC) was first introduced by Stan Davis in his book of 'Future Perfect'. He describes MC as a situation "*when the same large number of customers can be reached as in mass markets of the industrial economy and simultaneously they can be treated individually as in the customized markets of pre-industrial economies*"[1]. The term mass customization however has different understandings among the researchers. Certain believe the concept is only applied for product but to others, it also applicable for services. This particular study however will limit the concept to manufacturing of good [2].

This new production strategy rise up due to the intense competition in the industry and the opportunity opened up by technology advancement. With the development of new flexible manufacturing technology, the production of variety products easier than in the earlier days. On top of that, the development of the information system, making the communication

between the manufacturers and customers regardless B2B or B2C type of business become so much convenient. The distance between the two parties were reduced on a global scale in which the traditional boundaries of market has been erased. Hence, it leads to increased competition and the consumers able to choose from broader variety of products[1].

There are few distinctions that can be done between the mass production and mass customization concept which can be simplified as the table below:

Key factor differences	Mass production	Mass customization
Target customers or market	-Homogeneous customers -Large consumption market	-Heterogeneous customers
Skills	-low	-high/moderate
Manpower	Big	Small/medium
Layout	Product/ Line type	Process/Functional type
Production sequencing	-Shortest processing time (SPT) -Longest processing time (LPT)	Earliest due date (EDD)
Inventory	Build to Stock (BTS)	Build to Order (BTO)
Production and delivery times	Short	Long
Participation of the customers	Low	High

Table 2.1 Differences between mass production and mass customization

The conventional mass production is targeting a large consumption market, for instance commodity product, in which the prospective buyers of the product are found to be uniform in their needs, choices, habits or nature. Although, there might be some minor differences in terms of the design, quality and prices offered by different companies, most of the time, the products provide the same basic functions and usually compete only based on a few additional features.

The heterogeneous customers for mass customization concept on the other hand are very much more complicated. Contrary with the homogeneous, the needs of the customers are very wide. Hence market segmentation need to be done so that it can be divided into much smaller customers groups according to their similar homogeneous characteristics[3]. The needs, tastes and buying motives of each consumers are able to be identified, and subsequently, the marketing strategies and goal can effectively being carried out. The market segmentation usually being done by two basis, either consumer market or industrial market. The former referred to the division based on geographical, demographic, psychological or behavioral of the consumers while the latter referred to the type of the business itself [3].

Mass production require lower skill worker and bigger manpower comparing with the mass customization. Most of the task are repetitive and the whole production place are being departmentalized based on the task given. In contrast with mass customization, since it is a project basis kind of work, each of the order are usually different and the workmanship are being challenge. The manpower is much smaller and each of the worker should be able to handle any of the task as it is not fully departmentalized as mass production. The mass production worker are more prone towards work muscular skeletal disorder (WMSD) due to the repetitive task required while the mass customization might suffer the same but due

to different reason such as awkward posture, manual heavy lifting, and excessive use of vibrating hand tools.

Due to the cheaper labor of mass production concept, the manufacturers can offer much cheaper price. In fact, in United States, the downsizing of mass production of furniture industry are mainly due to the successful competition of low labor cost countries who enjoy significant price advantage in the US market[4]. Thus the domestic manufacturers considered the mass customization as a sustainable competitive advantage and as alternative to successfully compete in the future. They have bigger capabilities to do better at pre and post-sale services, delivery times and as well as the level of customization as they have advantage in terms of the proximity.

In terms of the layout of the production place, mass production is usually segregated based on the product type while the mass customization is according to the processes. Product or line layout usually limit the number of variation but offers the lowest cost of material handling. It fully utilize the machines capacity hence would be a great way to return high capital investment of a mass production. For production sequencing, it usually applies either shortest processing time (SPT) or longest processing time (LPT) in order to achieve the maximum possible efficiency[5].

However, the same type of layout will not be feasible to the mass customization concept. Since it does not involves as much repetitive work, they are usually departmentalized to smaller number of group but bigger in size for each. For example, for mass customization furniture manufacturer, they are being departmentalized according to the processes. One group for doing rough work as in plane or cutting, another group to do the sanding, another group for finishing and lastly for the assembly. As for the production sequencing, earliest

due date (EDD) is much more applicable hence the utilization of the machine might not be as great as the mass production[5]. Those that allow customization to the extent that they treat each of the project uniquely, the suitability of the machines arrangement might differ every time. Hence, the design of the workstation is very important in which certain machines are best to be mobile.

The mass production is using build to stock method (BTS) while the mass customization is using build to order (BTO). The former focuses on production even before the existence of demand for that particular product[6]. Historical sales data and forecast are being used to reduce the uncertainty demand. This type of method is susceptible to overstock if the sales are lower than the expected demand and lose out on sales if the demand is higher than the production. BTO method on the other hand, focuses on the production only after there is demand for that particular product. It gives bigger flexibility in production hence customizable products are feasible. BTO manufacturer does not have to worry on overstock of finished goods as the stock obsolescence risk has significantly reduced[7].

For the BTS, enterprise resource planning (ERP) used must be able to provide detailed data to get the most accurate sales forecast possible. While BTO, the ERP system must have a strong link between the sales order and the production department. Constant communication needs to be achieve to ensure the right specifications of the product[6]. The proper communication between the inventory and sales order department are also important in order to know which parts or components of the products are in high demand to avoid any unnecessary delay.

Proper mass customization is not only the matter of how customizable the product can offer but it is also include the delivery time and cost. In general, the more customizable it is, the

higher the lead time, the higher the cost. Hence a balance between the improvement of customization, responsiveness and cost-efficiency are the main key point to achieve. Thorough research on postponement strategies are needed and customer order decoupling point has to be determine (CODP)[8]. CODP is the point in supply chain where the customer's requirement are allowed to penetrate. Pre CODP usually where the mass production are still being implemented and are forecast driven while post CODP means the product links to a specific customer order. Sometimes, the CODP are being delayed till the end of the production process just to reduce the uncertainty demand.

There was a case study done on Norwegian furniture industry to identify guidelines in adopting mass customization in manufacturing enterprises. It was being conducted to two companies that have different outsets from mass production and handcrafted industry respectively. We are looking at the latter case as it is much more relevant to the study, company named Hagen, wooden staircase manufacturer in Sweden traditionally making the staircase fully customized, hence require high level of craft-work and manual operations. Although in such a way enable the enterprise to construct a perfect fit to particular measurement of staircase room, it is however too expensive and cumbersome to be successful especially in European market[1]. In order to adopt a mass customization strategy, they carried out range of improvement activities such as investment in much more flexible manufacturing system in which they shifted towards computer numerical control (CNC) machining. They also adopted Computer Aided Design (CAD) which in turn making the customer interaction during construction job much more efficient. Both of the case studies agreed that customization has to be done only to the components that gives added value to the customers. Modular products need to be establish in which certain components that does not require customization are being standardize. To reduce time

consumption, appropriate technology has to be used not only at the level of the production but also the inventory and responsiveness and interaction towards the customers[1].

2.3 Ergonomics risk in furniture workshop

Woodworking workshop are dangerous if not properly design. The workers are exposed to health hazard which can cause health impairment. They are not only vulnerable towards the danger of machine tools and cutting edges, but the wood itself can affect their health. In business perspective, with an ergonomics design of workplace, safer and more efficient jobs can be reach. It might be a bit tedious and cost a fortune to be implemented, but in the long run, the cost benefit would absolutely compensate the initial capital investment.

2.3.1 Work-related musculoskeletal disorder (WMSD)

WMSDs is an occupational injuries which caused pain or discomfort of the muscles, nerves, tendon or any supporting structure of the body[9]. It happens due to overuse of the musculoskeletal system and the injuries develop over time. Traumatic injuries does not considered as WMSD by most of health and safety agencies. However, the European Agency for Safety and Health at Work include acute trauma or fractures within the WMSD group[10]

336.75 among 10,000 workers every year are reported to have occupational illness and accident in woodworking industries as stated by the United States Department of Labor. Eight wood processing in southern Finland was reported to have 47 to 190 accidents among 1000 workers between the year of 1985 to 1989[11]. The figure might be much lower in

certain developing country, is not because it does not happen but lacking of available data and awareness on WMSDs.

The occurrence of WMSDs are due to the exposure of some risk factors which we can categorize into two. The first one is due to the work related ergonomic risk factor and the second one is individual related risk factors. The former include the task nature that require high number of repetition, forceful exertions or sustained awkward posture while the latter include poor work practices, poor fitness and poor health habits[12].

High repetitive manual work has been shown to affect neck, shoulder, arm and risk, depends on what body parts are involved. Repetitive contractions are believed to have higher risk factor of WMSDs comparing to the static one because of the delayed stimuli of interruption of the work task[13]. If the cycle time for the task is 30 second or less, it is considered as highly repetitive[12]. Awkward posture can lead to WMSDs when excessive force are exerted on joints and overload the muscles and tendons around the effected joints. Joints work the best when they operate at the mid-range motion of the joint or else it can become one of the risk factors of WMSDs[12].

Example of poor work practices that associated with the individual related risk factor is when the body mechanics and lifting techniques are wrongly used by the workers and introducing unnecessary stress which can cause fatigue and slows down their body's ability to recover[12].When fatigue outrun the recovery of the body, it leads to musculoskeletal imbalance. The overall body fitness and health habits are also important to the workers as they can fasten the recovery time.

Table below are among the frequent WMSD that occurred among workers in furniture industries.

Body Parts	Causing Factors	WMSD
Neck	Frequent extreme position of head	Cervical spine disorder
	Frequent extreme forward flexion	Cervical syndrome or radiculopathy
Shoulder	Repetitive arm movements	Myalgia in the trapezius muscle
	Prolonged forward flexion of neck	
	Prolonged arm raised and unsupported	Tendinitis in the shoulder muscle tendons
Arm, wrist and hand	Repetitive extreme extension of wrist	Lateral epicondylitis/tennis elbow
	Prolonged gripping	
	Repetitive hand movement (combine with force)	Carpal tunnel syndrome/tendon sheaths
	Prolonged wrist flexion	
	Prolonged use of vibrating hand tools	Vibration-induced white fingers
		Hand-arm vibration syndrome
Back	Manual material handling	Low back disorder
	Frequent forward flexion and twisting	
	Excessive whole body vibration	

Table 1.2 WMSD among workers in furniture industries

The causing factors can be overcome or minimize by having the right design of workstation, appropriate hand tools and conducive working environment.

2.3.2 Design of workbenches

The work height of the workbenches is very crucial especially for those doing repetitive work. If standing, the work height should normally be about the elbow level. If it is too high, the upper arm may be forced to be abducted or the ulnar deviate or palmar forced to flex the wrist. On the other hand, if the work height is too low, the workers may be forced to forward flex the back or head to radial deviate[13].

The work height of a workbench depends on the anthropometry of the woodworker, the type of task, the tools we are using and the size of the workpiece. If the woodworker most likely to do the same routine work, the design of each workbenches can be based on the type of work. The lower working height is best for heavy tiring work or any task that require the worker to get their body weight on the bench such as hand thicknessing[14]. While, when working with small and detailed things, a higher bench is much more favorable to save the back from stooping. If the fabrication may differ each time, it might be a bit impractical to set the work height based on a specific task. Each workbench has to be much more flexible either the height is made to be adjustable or set based on the size of standard machine instead. For instance, if the workbench is being used to become an outfeed of a table saw, it absolutely has to be lower than the machine itself. As the table saw usually come with a mobile cabinet or stand, the most convenient height of the machine has to be based on the anthropometry value of the woodworker. Ideally, the table saw's height has to be able to provide the upper body leverage over the work, so that the material can be push in comfort and maneuver in a better control by using upper body weight rather than arm muscles.

2.3.3 Hand tools design

It is recommended for a hand tool that have an index finger-activated trigger not to exceed 10 N for its trigger force. On the other hand those hand tools that have both the index and middle finger-activated trigger or four finger-triggered should not exceed 20 N and 30 N respectively. A hand tool design is also has to be made to minimize the required grip force during the task as repetitive gripping and increment in grip force will increase the risk of WMSDs [13].For both males and females, the optimal grip span in terms of the grip force is between 50 mm to 60 mm. The smallest possible grip movement is favorable as the greater one lead to greater total friction wear in the wrist and subsequently greater risk of tendinitis. Hand-maneuvered staple guns is one of the example of hand tools that have far too large of grip span or required grip movement.

Another point to consider is the external applied surface pressure (EASP) that the hand tools exerted on the palm and fingers. The pressure depends on the cross section, length , size or surface of the handle and trigger. Excessive force may cause pain and blisters. To prevent finger-trigger condition, the trigger has to always be operated by the middle of the finger instead of the distal-phalanx of the finger. The grip force shall always to be kept low in order to make sure low average EASP. Hence, the sharp edges of handles or triggers that form fitted handles, grooves or indentations should always be avoided. The length of the shanks or the triggers should also be appropriate as it may create high local EASP in the palm if they are too short. It is also recommended that the surface of the handle to be slightly compressible especially for striking tools such as hammer so that the pressure can be distributed more evenly in the hand.

Vibrating hand tools transmitted the vibration from the tool to the hand and it may be absorbed either by the hand or returned to the handle. The former will become another risk factor of WMSD such as HAVS. Higher frequency and lower push or grip force can decrease the transmission of vibrations from the handle to the hand. During prolonged gripping of power hand tools, the absorbed vibration energy increase although the grip force decreases.

The risk of Tendinitis increases when the biomechanical load on shoulder and load on the rotator-cuff tendons are high. These depends on the weight and lever of torque of the hand tool. The heavier and the longer the distance between the hand tools and the centre of gravity of the hand tool, the higher the biomechanical load[13].

2.4 Dust Control System

Major problem of woodworking regardless the area of the workplace is the dust control system. Some of small entrepreneur or hobbyist might take this for granted as it takes knowledge and cost them fortune to really have a dust free workplace. Hence they thought it would be sufficient enough to just wear a proper PPE and clean the saw dust simply by sweeping them which is obviously impractical and unhealthy. Jeopardizing one's personal health, fire safety and also cleanliness would never be worth it despite of how much the value of the business can turn into.

Sawdust is nuisance. Wood dust is first declared as carcinogen by the International Agency for Research on Cancer in 1994. It can interfere with human lung in variety of ways. The body's natural dust-ejection system will be affected and clog the natural cleaning action of

the lung's cilia. Hence, weakens the body's natural defense mechanism which overtime making the body much more susceptible to bacteria causing viral infection and illness. Chronic exposure to fine dust can even cause permanent lung damage due to the buildup of scar tissues. Based on the guidelines given by the Occupational Safety and Health Administration (OSHA), for an average small woodworking shop which is about 24 square feet garage, less than a gram of wood dust exposure are allowed for every 8-hours of workday .

Besides the health issues, dust control system is also important for safety measure of fire hazards. Any wood debris that piles up can easily be ignited. Sawdust can settle on hot light fixture or electrical junction boxes or around electric motors. It provides the necessary material to fuel a fire. Spark can occur due to faulty wiring or a grinder or even simply by switching on or off of a machine. It might be all it takes to cause deadly inferno of the woodworking workshop.

On top of that, without a proper dust control system, the machines will become less efficient. The machines are doing more work than what are necessary. For instance, the chips that are accumulated at the gullets of a table saw blade will be recut many times before cutting the new workpiece. Hence causing unnecessary heat buildup and dulls the teeth of the blade quicker than what it should be. The same thing are also applicable to other type of cutting machines such as router, miter saw, shaper cutters etc.

In order to figure out what would be the best way to overcome with the dust issue, it is vital to understand what type of dust we are facing as different type will require different

strategies of collection methods. Carpent Studio in particular, perform project based operation, in which the carpenters worked continually and the wood dust exposure is not uniform and might not be as typical as production line assembly type of operation

The most obvious and visible type of wood dust are the large shavings which produced by powered cutting machines like thickness planer or jointer or even hand tools like chisels or hand planes. These type are the most difficult of all wood waste to collect as it requires larger energy. Central dust collection system will need enough velocity and high volume of airflow to capture and transport them through the hoses and ductwork. Next is the chips or sawdust which more or less the size of shredded cheese. They are usually produced by smaller powered cutting tools like table saw, router or boring tools such as drills. Although the debris is relatively small, but it can pile up astonishingly fast. If not properly collected, an often used machine like table saw can collect the dust fast enough to clog the working parts. Lastly, the smallest but the most hazardous type of dust is the fine wood powder. While larger particles can easily falls onto the floor, these type of dust will be suspended in the air for quite a long time. Even the motion of the woodworker can stir up the dust. They are mostly produced by sanding wood or any power abrasive devices such as orbital sander, belt sander or even just hand sanding the wood by using the sandpaper.

Dust control system can be categorized into two which is the primary and the secondary system. The primary system will collect the wood debris directly after its being produced in which the collection compartment is connected to the tools either through flexible hoses or ductwork for instance, vacuum cleaner, portable dust collector and central collection system. The secondary system on the other hand includes the effort of controlling the dust

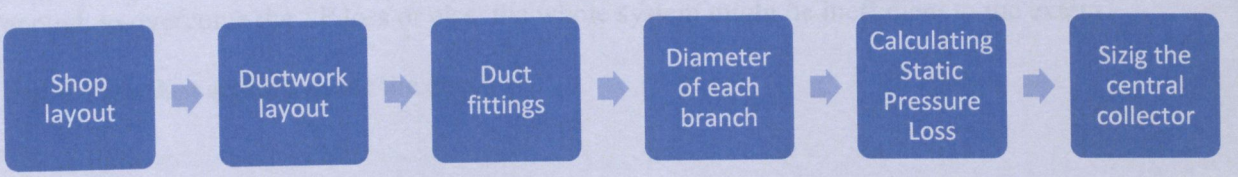
once they were released to the air such as the ventilation and air filtration of the woodworking workshop or the proper PPE such as mask and respirators worn by the production worker. Only the primary system will be discuss further as it is much more relevant with the objective of the study, designing a centralized dust control system.

Choosing vacuum for woodworking workshop isn't as easy as it thought it would be. Few things need to be taken into consideration depending on the purpose of the application. Basically, there are two main purpose of using vacuum in a woodworking workshop which are to do general clean up and also to collect dust from small or portable tools. In contrast with sweeping, vacuum does not raise up cloud of fine dust. In general, the features need to be considered are the vacuum power which associate with the suction and the airflow, the capacity and lastly the filtration. Picking up big size of wood debris for general clean up require big diameter of hose while to collect dust from the portable tools require much lower suction power hence smaller diameter of hose is ideal. On top of that, tool-actuated vacuums are much more favorable so there is no hassle of switching on and off of the vacuum as it will automatically turn to what the tools are currently in. For most woodworking workshop, vacuum would not be sufficient. For a better dust control system, portable dust collector can be used to handle bigger dust production. It has higher power and cubic feet per minute (CFM) and it employs a powerful induction motor. Comparing to the vacuum that use small universal motor, it is capable to draw in larger shavings that usually clog in the flexible hose of a vacuum. The fact that it is portable, it can be use whenever and whichever machines needed. Hence it is favorable by small size of woodworking workshop in which the mobility of each machines are very important.

The two type of primary dust management mentioned earlier, are considered insufficient for a dust free woodworking workshop. It is agreeable the best system will be the centralized collection system. The portable collector works just fine if it need to be connected to one or two machines, and only an individual working at a time. However, if there are many machines running at the same time, it might be a bit impractical. If space are not very much an issues, most of the machine can be stationary at one spot, and the centralized collection system can be implemented.

Centralized collection system comprises of the central dust collector, ductwork and the flexible hose. It begins from the hood or pick up from each machine which connected to the flexible hose. An air blast gate is used at the end of the hose to open or closes the airflow to that machine. Dust are then travel through the rigid ductwork and branches from smaller diameter to the bigger main duct that connect to the central collector. In order to achieve an efficient system, important things to consider includes the type of central collector, the network and diameter of the ductwork, the fittings to branches out the ductwork and material of the ductwork.

The process of designing the centralized dust control system can be a tedious work. In this particular study, it will be done by several steps which can be simplified as below:



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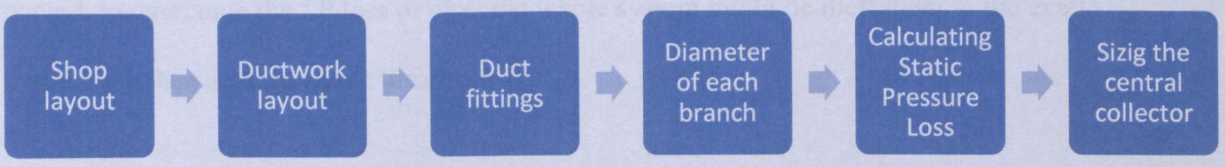


The shop layout proposed at the first part of the next chapter is used with some addition of location of permanent light fixture as well as structural elements such as beams, joists, plumbing or any electrical lines. Also, any points that the ductwork would interfere with the operation of the machine were noted. Before moving to the second step which was laying out the ductwork, the position of the dust collector was determined not only to ensure the efficiency of the whole system, but also to reduce the noise level and to properly routing the return air. The available space and the proximity of the dust collector to the machine were also taken into consideration.

Once the best ductwork layout has been determined, the appropriate fittings were chosen. They were used to change directions or make bends and they affect the friction between the air and dust as they passing through the system. Next, the diameter of each branch was determine based on the CFM requirement of each machine in order to ensure sufficient air were used to capture and transport the waste. An appropriate diameter of the ductwork is important in order to ensure the air moves at the right speed.

Lastly, to determine the performance figure of the collector, the resistance between the air and sawdust encounter when they passing through the system were calculated which measured as static pressure (SP) loss. It is essential to ensure the collector is powerful enough to overcome the SP loss or else, the whole system might be inefficient to the extent that the sawdust settling inside the ducts.

2.5 Types of Plant layout

There are 4 main types of layout which are:

I. Product or Line layout

II. Process or Functional Layout

III. Fixed Position Layout

IV. Combination Type of Layout (matrix or cellular)

The type of layout in a production plant depends on the type of industry and volume of production. Product or Line layout suitable for a standardized production which involves large quantities. The machines and equipment are arranged according to the sequence of operations in which the production line starts with the raw material at one end and goes from one operations to another till become the finished products[15].

The process or functional layout on the other hand, grouped the machines and operation facilities based on the type or function. For example, drilling machine at one space and grinding machine at another one. This type of layout offers bigger flexibility and commonly used for non-repetitive job and low volume of production. Fixed position layout place the product or component at a stagnant position either because it is too heavy or too big for instance in aircraft industry. The necessary tools and equipment are brought to the workplace along with the manpower.

Most of plant layout nowadays is not purely in one state. Usually if it does not involves enormous product, the production place operate in a combination layout, taking the advantages of both the product and process layout. Matrix layout are arranged in process

layout format but process grouping are arranged in a sequence. While the cellular layout, clubbed together components that require similar type of requirements and machines in a cell[15].

Layout usually are molded according to the requirements of the industry. The right layout design is important mainly to make sure the efficiency of the production floor by streamline the material flow, minimize the material handling cost, full utilization of cubic space, minimize the equipment investment and production time as well as ensuring safety and comfort of the employees.

The advantages and disadvantages of the layout can clearly be seen as in the table below:

Type of layout	Advantages	Disadvantages
Product/Line	-Low material handling cost -Good utilization of machines and labor -Less floor area needed -Minimized bottleneck , work stoppage is minimum -Minimize the production time -Cheap labor cost (routine task)	-Less flexibility -A single machine breakdown may affect the whole production line -Duplication of machines -High capital investment -Monotonous work
Process/Functional	-Greater flexibility in equipment and manpower	-Long material flow line -Expensive handling

	-Breakdown of any machine easy to be handle -Better control of complicated or precision process	-Production cycle time is high -More floor area is needed -Counting and scheduling is tedious
Fixed position	-Material movement is low -Greater flexibility for changes in product design -Capital investment is minimize	-Highly skilled manpower is needed -High movement time of machine to production point

Table 2.3 Pro and Cons of different type of layout

The important principles to consider in designing a plant layout are:

i. Integration
ii. Minimum distance
iii. Cubic space utilization
iv. Flow
v. Maximum flexibility
vi. Safety, security and satisfaction
vii. Minimum handling

Full utilization of the resources by integrating the manpower, material, machines can be achieve through a good layout. The facilities should be arrange in such that the distance need to be travelled by the workers and machines is kept at the minimum level

subsequently utilizing the cubic space. A bad layout will cause back-tracking of the material or work flow which in turns causing increment in production time. For future expansion, it is very important to have flexibility so it can be altered according to the requirements without much cost and time. For the well-being of the employee, consideration towards workers safety and satisfaction and safeguard the plants against fire and theft is also important[16].

2.6 Implementing Ergonomics in Carpent Studio

Carpent Studio has long being struggling to have a stable cash flow every month. One of the biggest issue was inefficient production due to improper workplace and mismanagement of timeline. Even though, the studio able to close enough projects, the timeline for each that sometimes drag quite significantly causing an instable cash flow. Hence an intervention of ergonomics in the production place is believe to give significant improvement directly to the timeline as well as the well-being of the workers and the stability of the enterprise as a whole.

Table below shows how the characteristics of MTO type affects ergonomics in the production place.

Characteristics of MTO	Ergonomic needs
Longer production timeline	-Delay of some furniture parts need to be expected hence a well organize storage as in easy access is necessary although the space does not have to be as big as MTS

Closer communication distance between manufacturer and client	-Production floor visit by customers are a norm, hence need to have much safer and convincing work place as in proper lighting and dust control
Process type of layout	-Longer material handling has to be expected as it is not one line production hence the space should be big enough and flexible to move
Flexible machining	-Possibility of correcting and re-do of the furniture has to be expected hence the place need to be able to safely move the product from one place to another without any tripping or accident.

Table 2.4 Ergonomic needs for MTO type of production floor

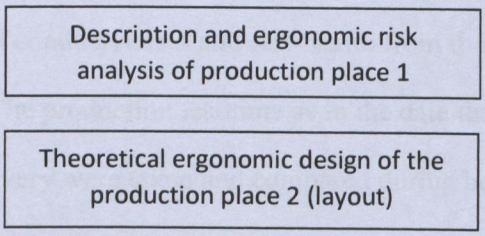
The table above explains that the nature of MTO requires certain ergonomic needs that have be taken into account in order to sustain. An ergonomically designed workplace especially in terms of the layout should never be taken for granted.

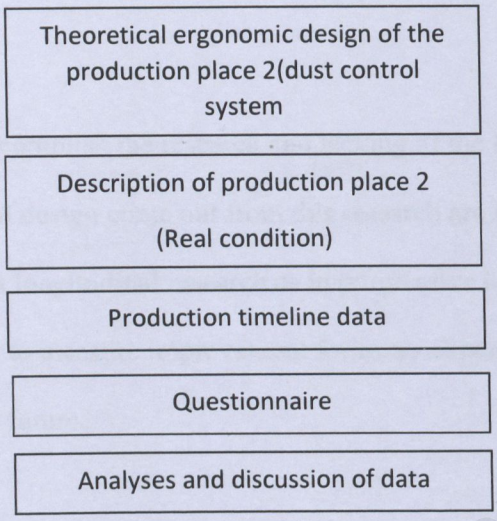
CHAPTER 3: METHODOLOGY

In this chapter, the methodology of the research will be presented. The research approaches will be discussed as well as the research design and method of data collection.

Research method

The research that being carried out is an applied or action research to find a solution for a small business organization. The main focus is to study the concept of mass customization and the efficiency of small furniture workshop. By using Carpent Studio as the case study, the ergonomics of former production place and the new one are being observed. With support from the previous literature and the critical discussion of the former workplace, the ergonomic design of the new production place as in the proper layout and environment are being carried out. Difference between the environment data collected before and after the move are observed. As a qualitative strategy, questionnaire for the customers during both of the workplaces was also being studied to investigate if there is any improvement in terms of the production timeline, quality and customer's satisfaction when the new design of the workplace are being implemented. The flow of the research project can be simplified as the diagram below:





Method of data collection

The ergonomics study that being carried out at both of the workplaces are in terms of the environmental data, proper layout and the design of dust control system. The environmental data comprises of light intensity, light position and the noise level. These values were taken by using the apps installed from the App store. The questionnaire to the customers comprises of 10 questions to measure the sought attributes for mass customization and the performance of Carpent Studio. The former is important in order to understand what needs to be prioritize and how to achieve it through the design of the workplace. While the latter is an important indicator to measure the efficiency of the production place by the customer's point of view. The interviews that being done to the workers comprises of few questions to measure the level of conduciveness and self-health from their point of view during both of the workplaces. The production leadtime as in the date that a project is allow to commence till the date of delivery were taken and compared during both of the workplaces.

Research quality

Due to short time required to accomplish the research and lacking of the funding and machine capacity, the theoretical design come out from this research are not being fully implemented. It is considered as longitudinal research as in progressive hence would be a good basis and a valid indicator to measure improvement for every expansion or changes of the business organization in the future.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Description of the former MTO setup (production place 1)

Carpent Studio started as a home-based furniture maker in Shah Alam on September 2017. The space during the time was very limited and not well segregated. Even though the whole space when sum up was more than a thousand square feet, the space that was really functional only about one third.

Referring to the floor plan (Figure 4.3), the area B which comprise of 224 square feet shade area was used as the main workspace. 8 feet by 4 feet workbench was placed at the center and become an out feed table for the table saw. For safety reason, whichever tools and machines that being used will be kept at the area C as it can be locked. The key point for this limited space was mobility. Caster was put underneath the table for the table saw so that it can be move to the main workbench when an out feed was necessary. The scrap storage was also made to be mobile so it can be put aside if bigger space for the project is needed.

Area C was about 150 square feet. The miter saw station was place and meant to be stationary. A folding and a big French door were purposely used so that an extra space can be used when a very long timber needed to be cut at the miter saw station. Most of the timbers were also kept in this space together with the finishing supplies and pegboard that full with power tools. The upstairs was the lounge area for the worker during the break. Area A was another extra space but did not have any shade. Space E was an extension part

of the house. The small room was the laundry room and the other part was being used as storage for the wood sheet supplies and finished product before they are being delivered.

4.2 Ergonomic Risk Analysis of the former MTO setup (production place 1)

One of the issues with the workplace was the inappropriate layout which in turns disrupt the workflow. The division of the room cannot be done properly due to the limitation of space. The basic workflow of the furniture fabrication which does not include the steel fabrication and upholstery part can be simplified as below.

i-Raw material	ii-Cutting, planing and machining	iii-Sanding	iv-Finishing	vi-Packaging	v-Assemble

The raw material has to be kept at the storage area. However, when the supplies were being delivered, there was no other access than to pass through the space A and work area B. During the cutting, planing and machining of the wood, the 8 feet by 4 feet wood sheet need to be carry again to the space B. The cutting, planing and machining processes involve so much of wood debris hence supposedly it requires a proper dust control system. Cutting process that use miter saw was being done at space C, while all the other process was at space B.

All the other processes were all being done at the same area. The process (ii) and (iii) are being done simultaneously but the finishing process has to be done separately. During the finishing, to make sure the outcome meets certain quality standard, the environment should be free from dust with temperate temperature and there should be no disturbance from any other means. During the finishing, other machining processes had to stop which obviously

causing delay and underutilization of the machines. Assembling and packaging processes were also being done at the area B and C before being kept again at the storage area E and ready to be delivered. During loading of the furniture for delivery, again they need to pass through the space D, B and A as that was the only access.

In terms of noise, the workplace had never received any complaints from the residents nearby. It might be because it's a corner lot house and directly besides the main road, hence the noise was a bit disregarded. During the operating hours, the works are being done by using the natural lighting. For the area that have walls, the natural light passing through the doors and the windows. The main working area B has a transparent roof but to avoid excessive heat, pine wood were used to become the ceiling. In any case that the work had to be done till late night, the light that being use is at mark position as in the floor plan.

Table below shows the light intensity at some point of the workplace

Position	Light intensity (LUX)
●	1594
●	5376
●	390
●	191

Table 4.1 Light intensity of production place 1

The main issues with the former workplace are:

i. Improper division of area causing underutilization of machines

ii. Limitation of space causing delay of process sequence

iii. Single access causing long material handling and inappropriate material flow.

iv. Improper dust control system

Figure 4.1 Production place 1 of Carpent Studio

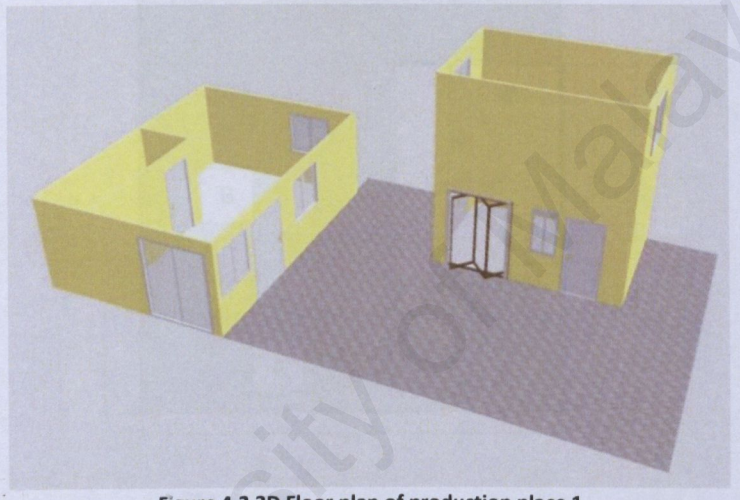


Figure 4.2 3D Floor plan of production place 1

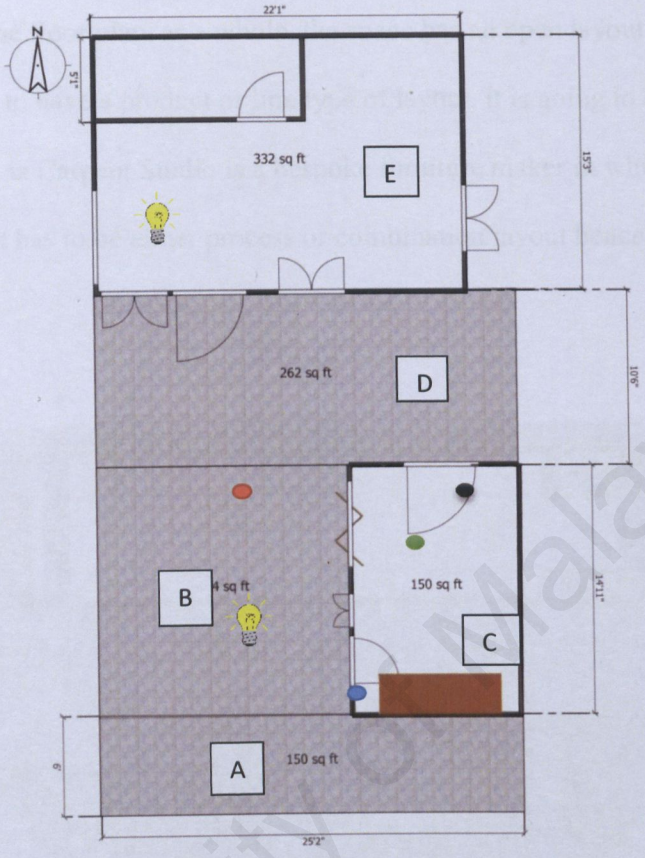


Figure 4.3 2D Floor plan of Carpent Studio

4.3 Design of new MTO setup (Production place 2)

The new workplace for Carpent Studio is located at a commercial lot in Glenmarie Industrial Park Shah Alam which has an area of 1609 square feet of ground floor and 481 square feet of mezzanine floor. The best way to have a good design of layout is by developing the layout first then only build the building around it rather than trying to fit the layout to the building that already constructed. However in this case, it has to be done as the latter since the small business has just started up and a big capital investment towards own construction would not be feasible.

As can be seen in the floor plan, as a whole, the space has an open layout that is long and narrow. If we were to have a product or line type of layout, it is going to be pretty straight forward. However, as Carpent Studio is a bespoke furniture maker in which produce product variation, it has to be either process or combination layout hence it is a bit challenging.

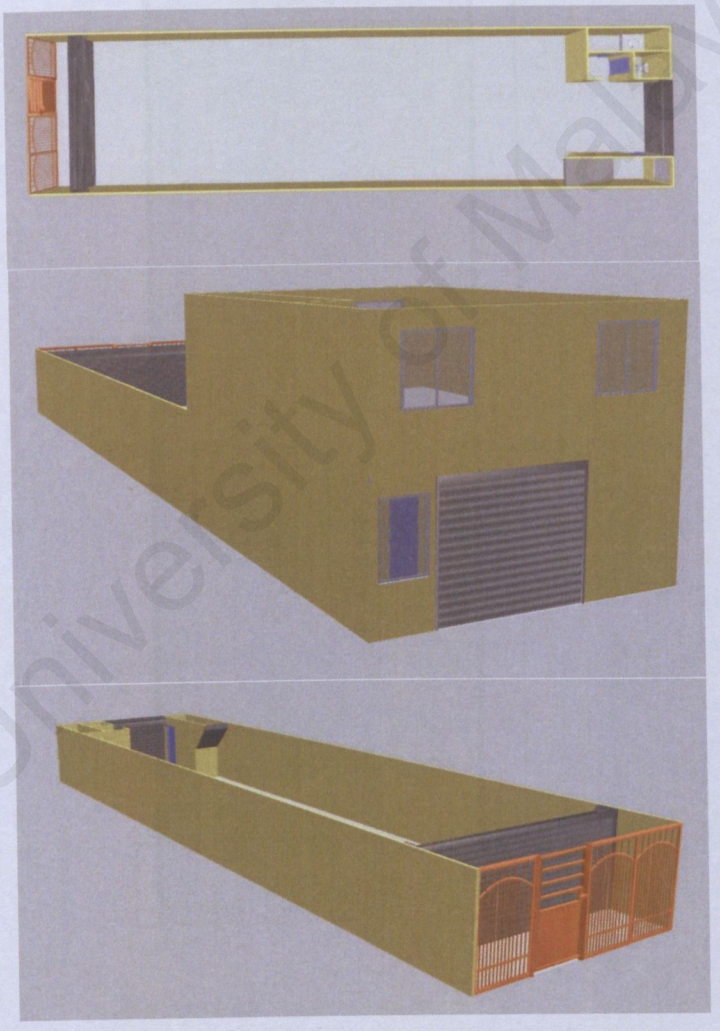


Figure 4.4 3D floor plan of production place 2

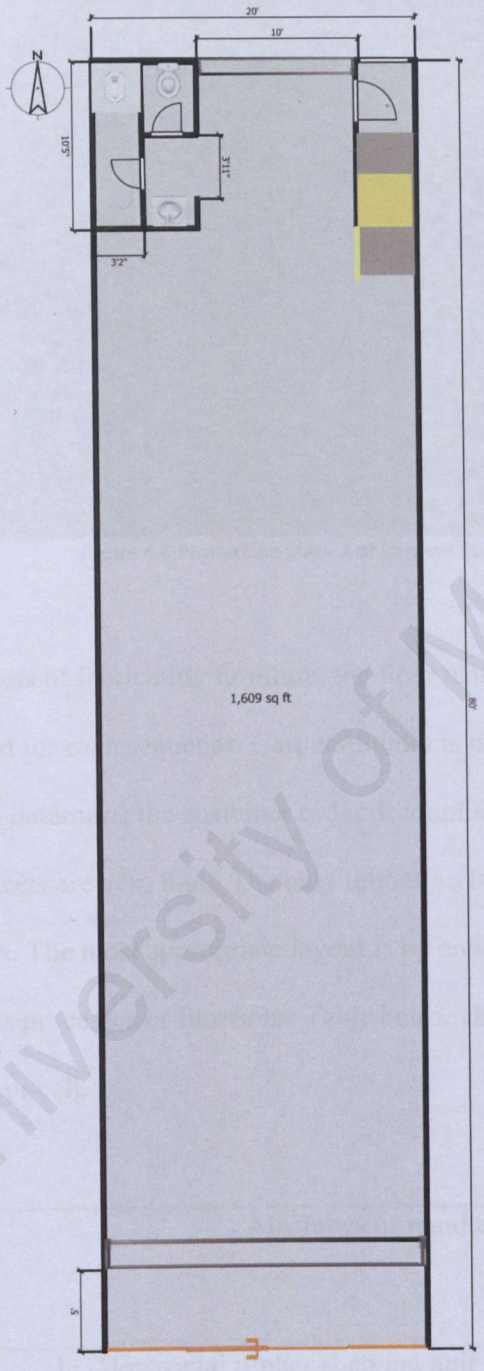


Figure 4.5 2D floor plan of production place 2

Figure 4.6 Production place 2 of Carpent Studio

Referring to the process of fabricating furniture, the floor plan should be divided based on the machines required for each sequence. Carpent Studio is now still using conventional machining and yet to determine the customer order decoupling point. Therefore, the variations of the projects are very high. The only limitation is the machine capacity and skill of the carpenters. The most appropriate layout is by creating cells that clustered machines based on its processes or functions. Table below shows the machines used for each type of process or cell.

Process/cell	Machines or required facilities
Raw material	1. Horizontal timber shelving unit 2. Vertical timber storage 3. Storage for 8feet by 4 feet wood sheet

Cutting, planning and machining	1. Wood jointer and planar 2. Wood thicknesser 3. Table saw 4. Mitre saw 5. Circular saw 6. Outfeed table 7. Bandsaw 8. Small cutting tools 9. Router table and trimmer 10. Bench drill
Clamping, jointing, gluing, laminating	1. 8 feet by 4 feet workbench 2. Compressor 3. Nail gun
Sanding	4 Belt sander 5 Belt/Disc sander 6 Orbital sander 7 Workbench or sawhorse leg
Finishing	1. Compressor 2. Spray tank 3. Stain and paint storage

	4. Workbench or sawhorse leg
Assemble	1. Impact/hammer/combi drill 2. Storage for fasteners,hinges,screw etc
Packaging	1. Wrapping machine 2. Boxes storage
Storage	1. Labelled shelving unit

Table 4.2 Machines and required facilities for each processes

Below shows the proposed division of cell according to the size of the commercial lot :

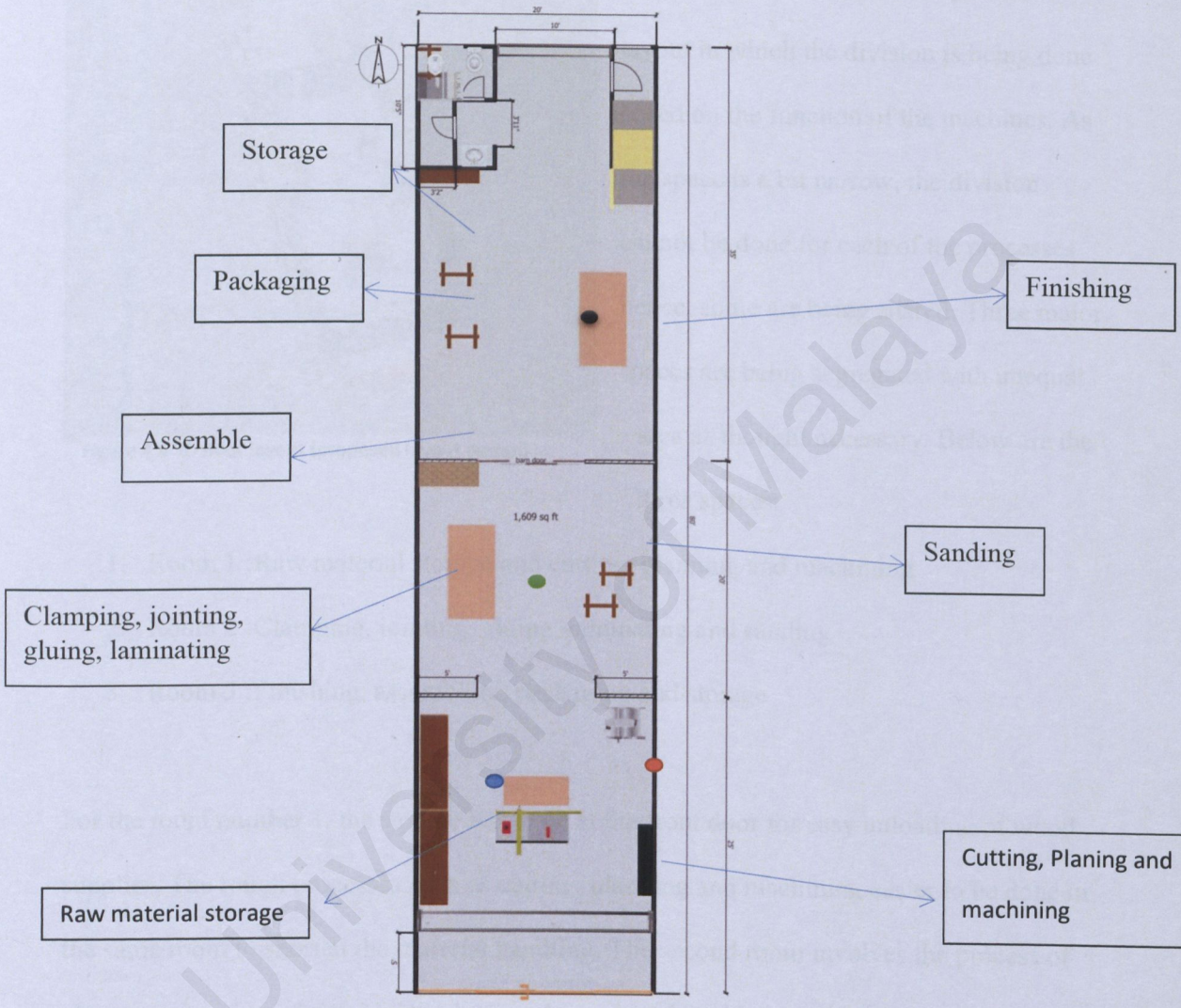


Figure 4.7 2D floor plan of production place 2 (proposed layout design)

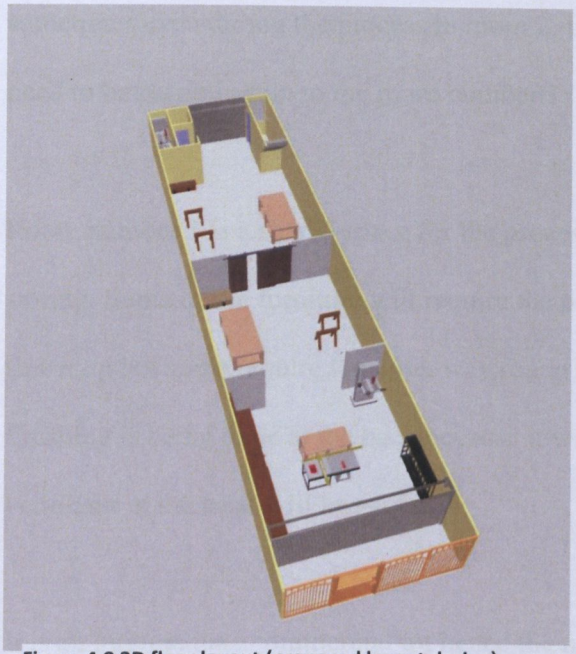


Figure 4.8 3D floor layout (proposed layout design)

Since Carpent Studio produces many variations of products, the type of layout proposed is the functional or processed layout in which the division is being done based on the function of the machines. As the space is a bit narrow, the division cannot be done for each of the processes hence, some are being shared. Three major spaces are being segregated with unequal area as thought necessary. Below are the three spaces:

1. Room 1 :Raw material storage and cutting, planning and machining
2. Room 2 :Clamping, jointing, gluing, laminating and sanding
3. Room 3 :Finishing, assembling, packaging and storage

For the room number 1, the storage has to be at the front door for easy unloading of wood supplies. The rough processes such as cutting, planning and machining easier to be done in the same room to shorten the material handling. The second room involves the process of clamping, jointing, gluing and laminating. It needs to be a bit far off from the machining part to avoid sawdust. The sanding process use the sawhorse instead of workbench to create flexibility as some of the furniture might need a bigger space and has to be put onto the floor instead of the workbench for example a king platform bed. The partition between the first and second room is intentionally to be without any doors for easy movement as

sometimes even during the process in room 2, there will be some changes and the material need to be carried again to the room number 1.

Room number 3 is a shared space for the process of finishing, assembling, packaging and storing. Some of the furniture will require the process of assembling and followed by finishing but some require the other way round hence its being done side by side. The finishing is being done at the back because it will involves process of spraying hence air ventilator at the back will be useful.

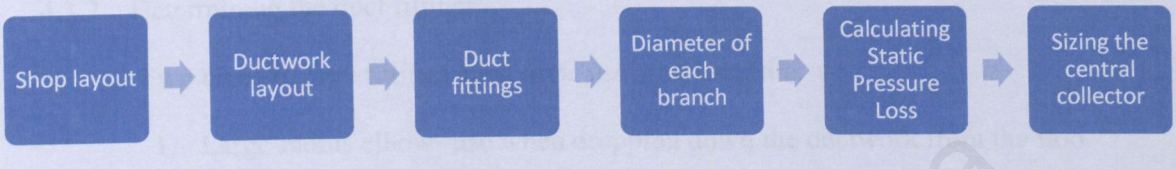
It is an intermediate commercial lot hence the natural lighting only come from the front and the back door. Sometimes the light has to be turn on even during the daytime. Below are table showing the light intensity at different position of the workshop (Referring to the diagram 5).

Position	Light intensity (LUX)
●	39
●	55
●	30
●	70

Table 4.3 Light intensity of production place 2

4.4 Centralized Dust Control System for new MTO setup (production place 2)

The centralized dust control system were designed according to this steps:



4.3.1 Setting up the shop layout

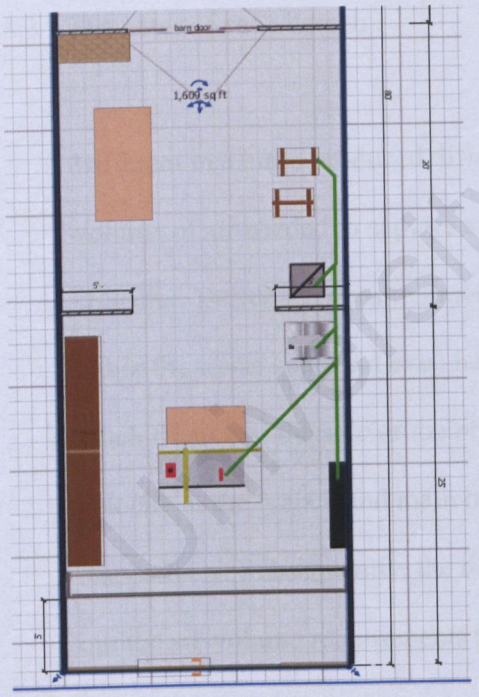


Figure 4.9 Ductwork Layout

Based on the earlier layout design, the light fixtures, structural elements and space for central collector were determine to be able to lay out the ductwork. More power required when the dust need to travel farther away from the machine to the central collector. Hence it is the best to keep the duct run as short as possible. As only the first two rooms produce so much of wood debris, the designed was being done within these two spaces. As the ceiling of the whole studio is way too high, the ductwork mostly attached to the wall with minimal to the high joist. The main duct runs from the central collector which placed in the second room and branch down to the machine it serves. To ensure efficiency of the

dust control, the ductwork run straightly and bend at 90 degree only when branching down to the machines except for the table saw as it needs to branch out diagonally before able to branch down to the machine.

4.3.2 Determining the duct fittings

Two types of duct fittings need to be use which are the:

1. Large-radius elbow- use when dropping down the ductwork from the floo to the machine
2. Wyes – use when branching the ductwork to different machines

4.3.3 Diameter of each branch

Different machines produced different amount of dust and chips hence different volume of air needed to capture and transport the waste to the centralized collector. Besides, air has to move at the right speed through the ductwork or else either the waste settle out even before they reach the collector or the air creates so much friction at the side of the pipe which may cause inefficiency. The best air velocity at the branch and main duct to convey dust is 4000 and 3500 feet/min respectively. Subsequently, the diameter of the ducts were determine by sorting out the air-volume requirements (in cfm) for each of the machine.

Room	Machine	Total CFM requirement	Branch diameter (inches)
1	Table saw	300-500	4-5
	Miter saw	300	4
	Band saw	300-500	4-5
	Router	350	4
	Drill press	350-400	4
	Planers	500-600	5-6
2	Belt sander	450-800	5-6

Table 4.4 Suitable branch diameter based on total CFM requirement of each machines

4.3.4 Calculating static pressure (SP) loss

Calculation of SP loss is important to avoid poor chip capture. It was done by using the worst case scenario in a one-machine-used-at-a-time system. Hence indicate how hard the collector's fan has to work when conveying dust from the branch with the greatest SP loss. The longest and smallest diameter with the most bends is the most likely to have the high amount of SP loss. In this study, the SP loss of the branch from the central collector to the table saw was calculated as it has the longest ductwork.

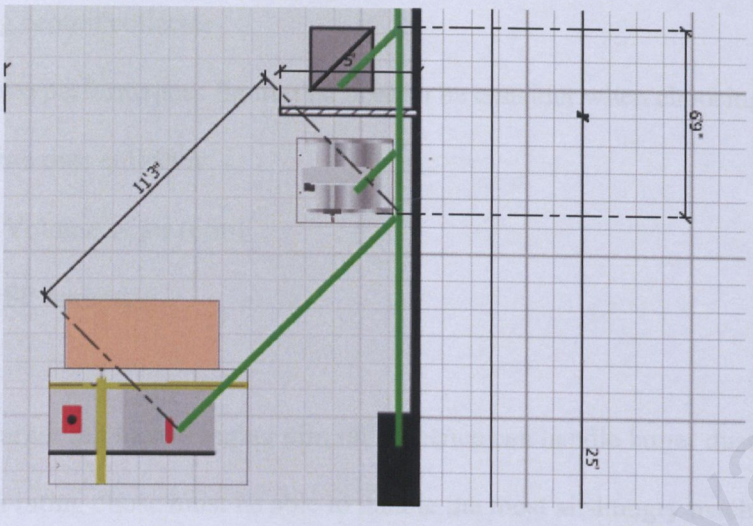


Figure 4.10 Ductwork layout

Source	Inches of SP Loss	
4inches branch duct	11.25ft x 0.070	0.7875
5inches main duct	6.75ft x 0.042	0.2835
4 inches flex hose (from table saw to ductwork)	2.5ft x 0.210	0.5250
6 inches flex hose (from collector to ductwork)	2.5ft x 0.105	0.2625
Fittings -1 x 90 degree elbow -1 x wye branch	(6ft + 5ft) x 0.070	0.77
Dirty filters and intake loss		3
	TOTAL	5.6285

Table 4.5 Inches of SP Loss

4.3.5 Sizing central collector

The two performances figure that need to be consider when choosing the best possible dust collector

1. Volume of air (cfm)
2. SP number

Collectors with larger fan have a higher cfm rating hence can handle larger dust output. In this case, the cfm rating chose must be able to handle the most air-hungry machine which is the belt sander. The SP number on the other hand is the number of inches of static pressure a collector is capable of generating. More powerful and efficient blower would have higher SP rating which means that it can handle longer ductwork system and greater air resistance.

4.5 Implementation of new MTO layout

Although the newly designed layout was thought to be the most practical for the size of the production place 2, however due to lacking of time and funding, not everything were managed to be carried out up to the end of the research project. As mentioned earlier, the research is progressive and need to be treated in such a way that it become a method of measuring the business improvement.

The process division were all being done as proposed except that it does not have the partition in dividing the area and the dust control system is still not able to be implemented.

4.6 Production Timeline of Carpent Studio

The usual lead time promised by Carpent Studio to the customers is 3 to 5 weeks. However, as each of the orders has its own level of difficulty in which certain has so much hiccups hence it is not necessarily the case. Below is data for the average lead time for each order from September 2017 to June 2018.

Month	Number of projects	Average number of days
September	7	34.3
October	4	20.5
November	6	17.5
December	10	38
January	6	33
February	1	47
March	6	25
April	17	32
May	7	27
June	5	15.8

Table 4.6 Average timeline for each project

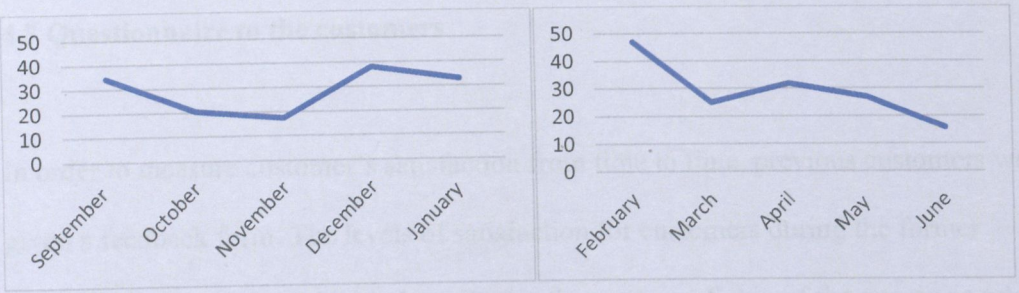


Figure 4.11 Average Production timeline based on month

Started with September, the average production timeline has become better but increase again in between November to December. This happen most probably due to the complicated order received by Carpent Studio for the first time. After December, Carpent Studio recruited another team member which explained the decrement as reaching to January. During February, Carpent Studio has started to make it moves from the production place 1 to production place 2, hence most of time were spent to set up the area rather than to chase for the deadline hence explained the significant peak during February. During March, the production place started to run smoothly but increase again during April as the project that coming in is so much bigger in number comparing to all the other months. Looking at the production timeline can be an indicator of the efficiency of the production place, however different factors also need to be taken into account for example the number of labor, the level of skills and the number of projects.

4.7 Questionnaire to the customers

In order to measure customer's satisfaction from time to time, previous customers were given a feedback form. The levels of satisfaction for customers during the former workplace were compared with those during the new one. Some of the questions asked might not be relevant to the study however will be useful for the development of the business. Below are the details for each of the questions and the comparisons of responses between customers during both of the workplaces. Customer1 and customer2 referring to the customers during the former and current production place respectively.

Question 1

How did you find out about Carpent Studio?

Figure 4.12 Result for question number 1

Diagram 1 illustrates how customers get to find out about Carpent Studio. Customers were given 5 alternatives to choose from: Instagram, Facebook, Carousell, Recommendations and others. All these alternatives have long become the marketing means or leads for the business even before the change in production place. Although the data could not become

an indicator to measure the efficiency of workplace, but it is important to understand which one is the most effective marketing medium.

Question 2

How important are the following attributes for your buying decision? (1 is not so important and 5 is very important)

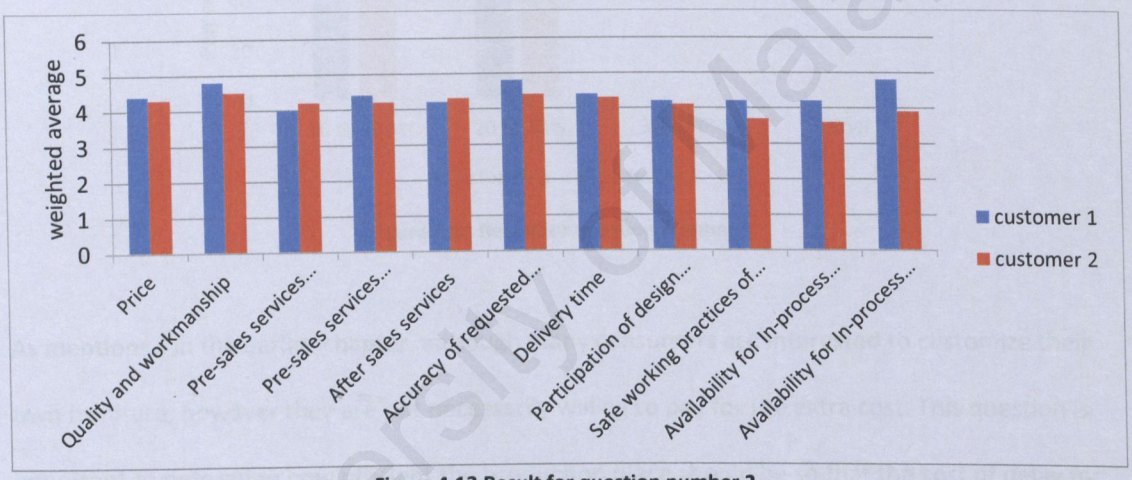


Figure 4.13 Result for question number 2

In this question, customers were asked which of these attributes important for their buying decision: Price, Quality and workmanship, Pre-sales services (Response time), Pre-sales services (consultation or suggestion in design, choice of material etc), After sales services, Accuracy of requested dimension and design, Delivery time, Participation of design process, safe working practices of the shop floor, availability for In process tracking, and availability for in process changes. Customers had to give value from 1 to 5 in which 1=Not important and 5=Very important.

Question 3

How much extra are you willing to pay to get customized furniture in comparison with the off-shelves furniture?

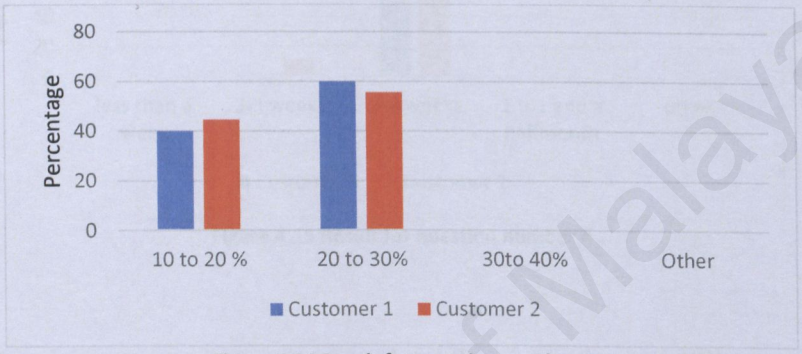


Figure 4.14 Result for question number 3

As mentioned in the earlier chapter, although many consumers are interested to customize their own furniture, however they are not necessarily willing to pay for the extra cost. This question is important to determine how efficient the production place should be so that the cost of delay for customizing a product can compensate by the extra cost paid by the customers in comparison with the off shelves furniture.

Question 4

How long are you willing to wait for made to order furniture rather than getting a ready stock one?

Figure 4.15 Result for question number 4

This question is important to determine how long the customers are willing to wait. By knowing the acceptable duration, the amount of monthly sales that need to be done and the production capacity can be determined.

Question 5

Which customer's interaction suits you the most?

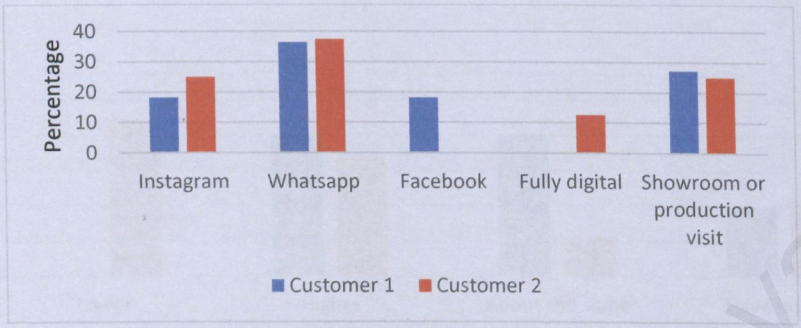


Figure 4.16 Result question number 5

This question is important to determine the favorite customer's interaction so that the communication between the customers and manufacturer can be much easier. To fabricate a customize product, a smooth communication method need to be adopted.

Question 6

Compared to other furniture maker, is our product quality better, worse or about the same?

Figure 4.17 Result question number 6

Responses to this question can also become an indicator of customer's satisfaction.

Question 7

Compared to other furniture maker, our prices are lower, higher or about the same?

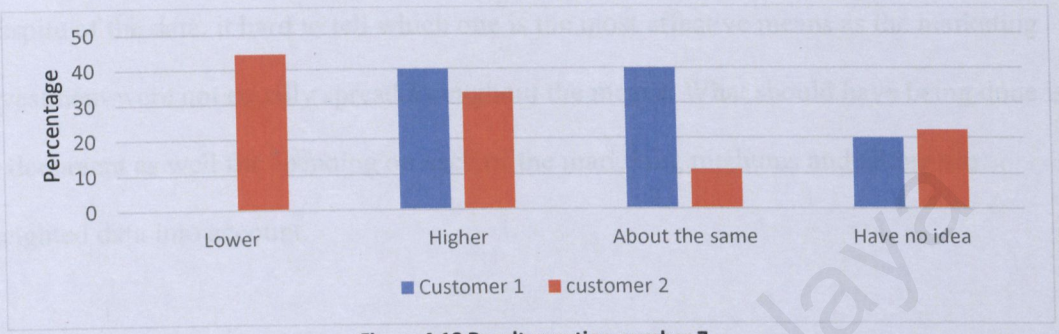


Figure 4.18 Result question number 7

Although this question might not be related to the study, but for the business development, it is important to know whether or not the company has price competitive advantage.

Question 8

How likely are you going to recommend Carpent Studio to your family and friends?

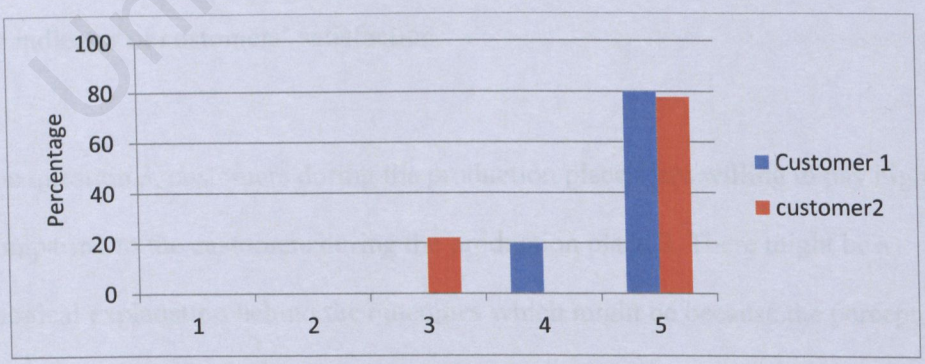


Figure 4.19 Result question number 8

This question is important as an indicator of customers' satisfaction.

4.7.1 Analysis of questionnaire

Based on question 1, customers during production place 1 spread evenly except for Facebook while for customer during production place 2 was mostly from Instagram. Despite of the data, it hard to tell which one is the most effective means as the marketing investment were not equally spread throughout the means. What should have being done is to document as well the spending on each of the marketing mediums and taking the weighted data into account.

Question 2 was a bit hard to analyze as most of the customers giving 5 for all the attributes. Hence we cannot really determine which attributes are the most important to the consumer. If question were to be change, it should be asking the ranking for each of the attributes instead. But if the respondents are not big enough, variations in terms of the data will be big. Hence to overcome that, the attributes question should remain as it is but there should have been an extra question on what level Carpent Studio has live up to their expectations regarding those attributes. From there, correlation between the importance of the attributes and level of what they had experience could be determine and subsequently become a stronger indicator of customers' satisfaction.

Based on question 3, customers during the production place 1 are willing to pay higher price comparing to the customers during the production place 2. There might be a psychological explanation behind the outcomes which might be because the perception of the customers looking at the size of the business during both of the production place. Although for a matter of fact, the production place 2 had to bear much higher of overhead

cost. Question 4 was asked to determine the willingness time of waiting. Customer's during production place 1 is willing to wait for a longer time comparing to the customers in production place 2. The outcome is valid as the production place 2 should have manage to shorten the lead time as the efficiency should have improved.

One of the important elements in MTO is the communication between the fabricator and customers as the participation of customers throughout the project is important. Based on question 5, during both of the workplaces, customers found that Whatsapp is the most reliable medium to communicate and fully digitalize website is found to be the least preferred medium. As tedious as it may sound, for future expansion of the business, rather than investing in having fully digitalize order flow, it may be an important things to remember that customers prefer to have a medium that easy to explain either by writing or verbally explaining it.

Question 6 and 7 were asked to know where Carpent studio stands relative to their competitors in terms of the pricing and quality. Most of the customers during the production place 1 felt the studio's price is higher and better quality while customers during production place 2 think the price is lower but the workmanship to be better or more or less the same with other customize furniture maker. The last question is to indicate the overall customers' satisfaction. It was found that customers are more satisfied during the production place to compared to 1.

CHAPTER 5: CONCLUSION

From this research project, it was found that the most practical production layout for Made to Order (MTO) type is the functional layout in which the machines are clustered together based on its function and process that requires them. A better solution for an improved material handling, smoother workflow and safer workplace from a home based MTO setup to a proper small workshop were identified. Proper dust control system was designed and it was found that the practical way to implement it is by placing the centralized collector at room 2 with air flow of at least 800 cubic feet per minute and Static Pressure (SP) rating to be more than 5.63.

In order to measure the efficiency of the production place, there must be some method to quantify it. In this particular study, the production timeline and customers' satisfaction were being analyzed. However, there are not strong enough to become an indicator due to changes that also become factors for the production timeline such as changes in number of labor and addition of the machines. The questionnaires has a lot of room for improvement in order to gain much more useful data for a valid and stronger justification.

For future improvement, the proposed design should be fully implemented and the production timeline has to consider the changes in the business throughout that certain period. The questionnaire on the other hand should be reconstructed in such a way to gain much more valid data.

REFERENCES

[1] L. Skjelstad, I. Hagen, and E. Alfnes, "GUIDELINES FOR ACHIEVING A PROPER MASS CUSTOMISATION SYSTEM," no. Mc, pp. 1565–1572, 2000.

[2] "Mass Customization," no. 1993, pp. 23–41, 2011.

[3] Aprameya joshi, "Market Segmentation." [Online]. Available: https://www.slideshare.net/aprameyajoshi/market-segmentation-37329823. [Accessed: 18-May-2018].

[4] F. C. Corp and R. Beauregard, "Mass customisation of wood furniture as a competitive strategy Torsten Lihra * Urs Buehlmann," vol. 2, pp. 200–215, 2008.

[5] S. Wilson, "Sequencing in Process Manufacturing – The Product Wheel Approach," pp. 1–10.

[6] A. Continelli, "Build-to-Stock or Build-to-Order?," *Cre8tive Technology and Design*, 2017. [Online]. Available: https://advancedmanufacturing.org/bto-or-bts/. [Accessed: 22-May-2018].

[7] "T6: Mass Customization, Build-to-Order Manufacturing, and Personalization," *Pearson*. [Online]. Available: http://wps.pearsoned.co.uk/ema_ge_turban_elec_comm_2012/217/55592/14231619.cw/content/index.html.

[8] Y. Qin and Y. Geng, "Production Cost Optimization Model Based on CODP in Mass Customization," vol. 10, no. 1, pp. 610–618, 2013.

[9] N. M. Nur, S. Z. Dawal, and M. Dahari, "The Prevalence of Work Related Musculoskeletal Disorders Among Workers Performing Industrial Repetitive Tasks in the Automotive Manufacturing Companies," pp. 1–8, 2014.

[10] "Work-related Musculoskeletal Disorders (WMSDs)," *Canadian Centre for*

Occupational Health and Safety. [Online]. Available: http://ccohs.ca/oshanswers/diseases/rmirsi.html. [Accessed: 26-May-2018].

[11] B. S. Polytechnic and M. Faculty, "ERGONOMICS WORK STATIONS DECREASES THE HEALTH IMPAIRMENT AND SAVES ELECTRICAL ENERGY AT THE WOODWORKING WORKSHOP IN BALI , INDONESIA," no. December, pp. 41–54, 2012.

[12] M. Middlesworth, "The Definition and Causes of Musculoskeletal Disorders (MSDs)." [Online]. Available: http://ergo-plus.com/musculoskeletal-disorders-msd/. [Accessed: 26-May-2018].

[13] G. Bjoring, "Ergonomics in the wood-working industry," vol. 2, p. 70, 1998.

[14] "Rule of thumb guides best workbench height." [Online]. Available: https://www.woodmagazine.com/workbench/rule-of-thumb-guides-best-workbench-height. [Accessed: 28-May-2018].

[15] B. Smriti and C. Plant, "Four Main Types of Plant Layout," no. i.

[16] A. Kumar, "Plant Layout • Plant layout is a plan of an optimum arrangement of facilities including Plant Layout & Its Objectives Plant Layout • Plant layout is the physical arrangement of Objectives of Plant Layout Factors Affecting Plant Layout Factors Affecting Plant Layout © Copyright 2013 Anupam Kumar Factors Affecting Plant Layout Factors Affecting Plant Layout Factors Affecting Plant Layout Principles of Plant Layout • To ensure the smooth functioning of a plant , … Principles of Plant Layout • Principle of Integration Principles of Plant Layout • Principle of Cubic Space Utilization – A good layout is one that utilized both the – A good layout makes the material move in the • Principle of Minimum Distance – The facilities should be arranged such that the • Principle of Maximum Flexibility – A

good layout can be altered without involving © Copyright 2013 Anupam Kumar," pp. 1–3, 2013.